Program Digest, 2019 IEEE International Ultrasonics Symposium (IUS)
Glasgow, Scotland, October 6-9, 2019

Construction of an ultrasound phantom with micrometer-sized wall-less vessels

Benjamin Meirza
Dept. of Biomedical Engineering
Faculty of Engineering, LTH,
Lund University
Lund, Sweden

Hideyuki Hasegawa
Graduate School of Science and Engineering,
University of Toyama
Toyama, Japan

Maria Evertsson
Dept. of Biomedical Engineering
Faculty of Engineering, LTH,
Lund University
Lund, Sweden

Sandra Sjöstrand
Dept. of Biomedical Engineering
Faculty of Engineering, LTH,
Lund University
Lund, Sweden

Magnus Cinthio
Dept. of Biomedical Engineering
Faculty of Engineering, LTH,
Lund University
Lund, Sweden

***Abstract*—The development of new ultrasound imaging technologies that aim to resolve objects smaller than the conventional ultrasounds diffraction limit calls for new types of phantoms to evaluate these technologies. When it comes to vascular flow phantoms, this becomes challenging due to the difficulty of manufacturing phantoms with vessels smaller than 1 mm in diameter. Here we describe a novel manufacturing method to construct phantoms with micro-vessels with a size down to 88 µm using oil-based clear ballistic gel (Clear Ballistics, Greenville, SC, USA) as surrounding material. Clear ballistic gel is a long-term stable tissue-mimicking material with speed of sound around 1470 m/s.**

Keywords—phantoms, ultrasound, vessels, wall-less, clear ballistics gel

I. Introduction

Microflow ultrasound imaging, contrast-enhanced ultrasound, and super-resolution ultrasound imaging are all emerging technologies within the medical ultrasound field. Recently, Christensen-Jeffries et al. visualized the microvasculature of a mouse in vivo using microbubbles at a very high spatial resolution beyond the diffraction limit of ultrasound by localizing echoes from microbubbles [1,2]. Also, it has been proven that high-frame-rate ultrasound can enhance image quality in microvascular imaging with microbubbles [3].

Vascular phantoms are an important tool in clinical training, when testing invasive medical devices and when evaluating new medical imaging systems. To evaluate the emerging technologies mentioned above, phantoms with very small vessels are desirable. It is, however, challenging to manufacture such phantoms and to overcome this difficulty one might resort to incorporating small vessels without a vessel wall in hard material, or, using vessels with disproportionately thick walls. Both scenarios will give rise to unwanted hyperechoic areas in the ultrasound images, which makes it hard to visualize the vessel.

The ideal tissue-mimicking material for constructing ultrasound phantoms should have the same ranges of attenuation, scattering coefficients and the sound velocity as tissues. These parameters should preferably be controllable in the material preparation process, and further the phantom material should be temporally stable in room temperature, as well as have no specific restrictions for storage. A wide range of soft tissue-mimicking material, such as agarose, gelatine, polyvinyl alcohol, and tofu, have been employed in ultrasound phantom fabrication [4]. These materials are water-based and are thus, sensitive to dehydration and not stable over time. To overcome this problem, oil-based phantom materials such as Styrene Ethylene Butylene Styrene (SEBS) copolymer mixed in mineral oil, has been developed [5,6]. However, the oil-based materials have a somewhat lower sound propagation velocity compared to the water-based.

Recently, we have evaluated the potential to use oil-based ballistic gelatine (Clear Ballistics, Greenville, SC, USA) as tissue-mimicking phantom material. The ballistic gelatine is easy to use, long-term stable, has an attenuation comparable to soft tissue, and a speed of sound of approximately 1470 m/s, which is within reasonable range compared to the 1540 m/s, usually employed as an approximate mean value for soft tissue. In this study we have used this material to create ultrasound flow phantoms.

The aim of this work was to develop a wall-less micro-flow phantom with micro-vessels with a diameter much smaller than 1 mm in diameter.

II. Materials and Methods

A. Mold preparation

To manufacture a phantom with four wall-less vessels, a 45 x 45 x 25 mm sized stainless steel mold with a removable bottom was created. Four holes, 200 µm in diameter, were drilled at two opposing ends of the phantom mold and four syringe needles were inserted in the holes at one end. To create the vessels, an 88 µm in diameter copper wire was attached and stretched between the two ends, though the syringe needle and the corresponding hole.

B. *Phantom material preparation*

Clear ballistic gelatine gel (Clear Ballistics, Greenville, SC, USA) was melted in an oven (Nüve FN300, Nüve, Ankara, Turkey) at 130°C. When the ballistic gel was completely melted, graphite powder (Merck, Darmstadt, Germany) (4.5% weight percent) was added to act as a scattering media in the ultrasound images. To remove air bubbles, the mixture was again placed in the oven for an hour. The mixture was thereafter gently poured into the phantom mold, and to make sure that no air bubbles were trapped, the phantom mold was placed in the oven for an additional hour. Afterward, the phantom was cooled in room temperature and when it was room tempered the wires were removed and the wall-less vessels were formed.

C. *Ultrasound visualization*

The phantom was imaged using a 21-MHz transducer attached to a Visualsonics Vevo 2100 (Visualsonics Inc, Fujifilm, Toronto, Canada). Water was filled into the vessel channels through the syringe needle in order to illustrate blood, and to overcome the mismatch in acoustic impedance between air and the phantom material.

III. Results

Figure 1 shows an early prototype of the mold and the four copper wires attached between the two ends. This mold is made out of cardboard, but in order to remove potential trapped air bubbles, arising when the solution was poured into the mold, the material of the mold had to be changed to something more heat-resistant. The final stainless steel mold and the phantom is shown in Fig. 2. Figure 3 shows a high-resolution ultrasound image of the wall-less micro-vessel phantom during pulsatile flow. The micro-vessel is positioned at 16 mm depth and has a diameter of approximately 0.1 mm. The syringe needle is shown to the left in the image.

IV. Discussion and conclusion

In this study, we have developed a novel manufacturing technique to construct temporally stable micrometer-sized wall-less vessel phantoms using clear ballistic gel as phantom material. The diameter of the vessels created herein was 88 µm

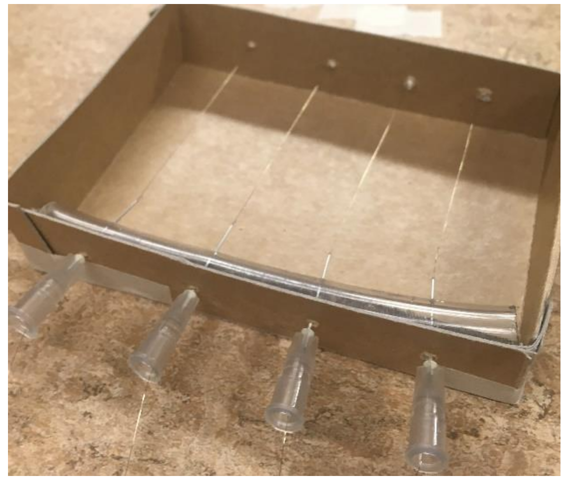

Fig. 1. An early prototype of the phantom mold.

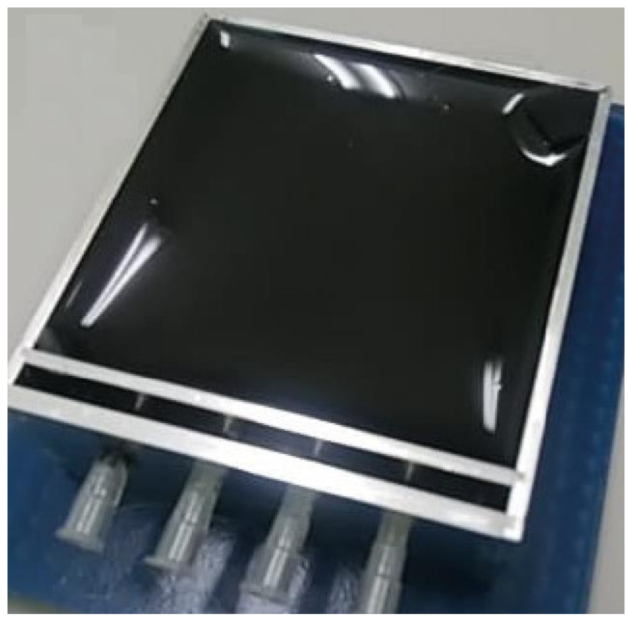

Fig. 2. The final metal mold and phantom. An easy way to remove unwanted air bubbles was to place the mold with phantom material mixture in the oven for an hour.

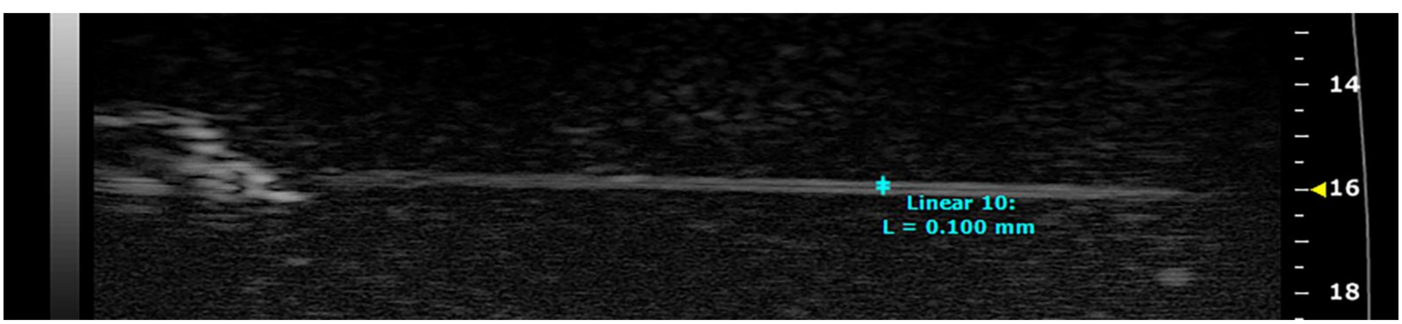

Fig. 3. A high-resolution ultrasound image of the wall-less micro-vessel phantom during pulsatile flow. The micro-vessel is positioned at 16 mm depth and the syringe is shown to the left. The caliper show that the inner diameter is appoximately 100 µm.

but the vessels can probably be made even smaller if a durable wire is accessible, which makes this manufacturing technique very adjustable and useful. Even though the vessel channel is clearly seen in the high-resolution ultrasound image, there are distinct ultrasound echoes along the vessel wall. This may be a result of graphite accumulation close to the copper wire during the heating and solidification process. Further investigation has to be made in order to ensure if this is correct and also in order to see if the strong echoes can be removed or be diminished if this may be needed in some imaging applications.

The novel phantom type developed in this study can be used in many different fields of applications but it would be especially valuable during development and evaluation of the emerging technologies, microflow ultrasound imaging, contrast-enhanced ultrasound, and superresolution ultrasound imaging.

REFERENCES

[1] O. M. Viessmann, R. J. Eckersley, K. Christensen-Jeffries, M. X. Tang, and C. Dunsby, "Acoustic super-resolution with ultrasound and microbubbles," Physics in Medicine and Biology, vol. 58, pp. 6447-6458, 2013.

[2] K. Christensen-Jeffries, R. J. Browning, M.-X. Tang, C. Dunsby, and R. J. Eckersley, "In vivo acoustic super-resolution and super-resolved velocity mapping using microbubbles," IEEE Transactions on Medical Imaging, vol. 34, pp. 433-440, 2014.

[3] A. Stanziola, C. H. Leow, E. Bazigou, P. D. Weinberg, M. Tang, "ASAP: super-contrast vasculature imaging using coherence analysis and high frame- rate contrast enhanced ultrasound," IEEE Transactions on Medical Imaging, vol. 37, pp. 1847-1856, 2018.

[4] M. O. Culjat, D. Goldenberg, P. Tewari, and R. S. Singh, "A review of tissue substitutes for ultrasound imaging," Ultrasound in Medicine & Biology, vol. 36, no. 6, pp. 861–873, 2010.

[5] J. Oudry, C. Bastard, V. Miette, R. Willinger, and L. Sandrin, "Copolymer-in-oil Phantom Materials for Elastography". Ultrasound in Medicine & Biology, vol. 35, no. 7, pp. 1185–97, 2009.

[6] L. C. Cabrelli, P. I. Pelissari, A. M. Deana, A. A. Carneiro, T. Z. Pavan, "Stable phantom materials for ultrasound and optical imaging", Phys. Med. Biol., vol. 62, pp. 432–447, 2017.